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A PSYCHOPHYSICAL STUDY OF THE RF SOUND PHENOMENON

A. Frey, R.Messenger, E. Eichert

Final report, June, 1972

U. S. Army Mobility Equipment Research
and Development Center
Fort Belvoir, Va. 22060
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Randomline, Inc.
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13. ABSTRACT

The objective of the experimentation reported herein was to obtain additional data on the rf sound phenomenon. This phenomenon is the perception of what is reported to be a sound when the head is illuminated with rf energy of particular characteristics. In the first phase of the experimentation, we assembled a portable rf sound demonstration unit. This was successfully used to demonstrate the phenomenon and its characteristics. In phase two, we determined what rf parameters are relevent to generating the perception of rf sounds of significance. We learned enough in this phase to successfully create a perceived sound that we desired to create. In phase three, we explored the possibility of determining if the perception of speech could be induced. It was found that aspects of vocoder technology could not be used to generate speech. It was also found that perceived rf sound can not be generated using the rules of the periodicity pitch phenomenon.

Key words - rf sound, microwaves, hearing, sound, nervous system, sensor, periodicity pitch, psychophysics.

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SUMMARY

The objective of the experimentation reported herein was to obtain additional data on the rf sound phenomenon. This phenomenon is the perception of what is reported to be a sound when the head is illuminated with rf energy of particular characteristics. In the first phase of the experimentation, we assembled a portable rf sound demonstration unit. This was successfully used to demonstrate the phenomenon and its characteristics. In phase two, we determined what rf parameters are relevant to generating the perception of rf sounds of significance. We learned enough in this phase to successfully create a perceived sound that we desired to create. In phase three, we explored the possibility of determining if the perception of speech could be induced. It was found that aspects of vocoder technology could not be used to generate speech. It was also found that perceived rf speech can not be generated using the rules of the periodicity pitch phenomenon.

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INTRODUCTION

The perception of what is reported to be a sound when the head is illuminated with rf energy of particular characteristics is defined as rf sound. These characteristics include very low (microwatt/cm^2 level) average power densities, carrier frequencies in a band from 0.4 GHz to 3 GHz and specific modulations. The nature of the sound is related to properties of the pulse modulation of the rf energy. Pulse widths between 2.5 μs and 2000 μs and pulse rates between 1 and 400 pulses per second have been used to induce the sound-like sensation in humans. The sensation is reported by people to be a buzzing, clicking, or hissing which seems to originate (regardless of the person's position in the field) within or just behind the head. The crude thresholds that were found in past studies are shown in Fig. 1. The experimental arrangement ruled out explanations of the phenomena such as rectification by fillings in the teeth. The most sensitive area was the region over the temporal lobe

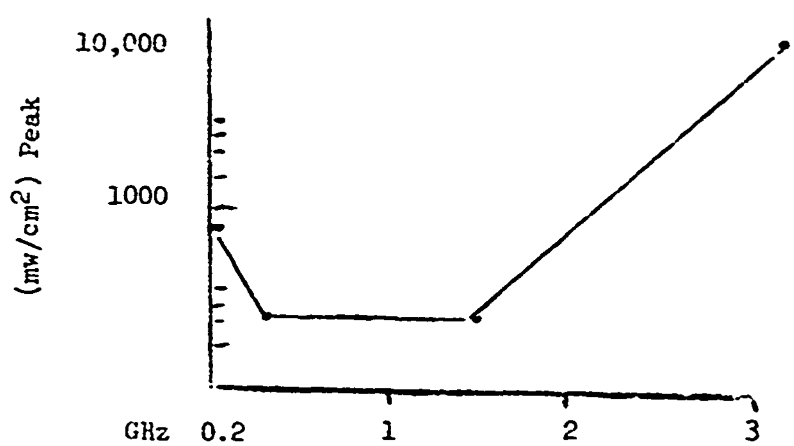

Fig. 1 Preliminary thresholds for rf sound as a function of rf energy.

of the brain.

Initially this writer felt that the rf sound effect and the electrophonic effect might be comparable, and that a technique had been found that could be used to explain the electrophonic effect (stimulation of sensation in the auditory system with electric current). The writer pursued experimental studies which indicated that the rf sound effect and electrophonic effect are not the same phenomenon. Mathematical analyses were also carried out to consider the possibility that vibration of the skin due to rf radiation pressure might account for the effect. The results indicated that radiation pressure could not account for the effect.

In an attempt to locate the sensor, a search was undertaken for cochlear microphonics in guinea pigs and in cats exposed to rf energy. No cochlear microphonics were found in either species. Control tests with acoustic energy of comparable waveform and loudness, including the alternation of acoustic and rf energy, indicated that a microphonic does not occur with rf energy. The power densities used were far above that needed to induce the auditory effect in cats. This would suggest that the sensor may not be prior to the inner ear.

Based upon the foregoing, an experimental program was undertaken to elicit additional information on the phenomenon. The program was developed in three phases and the results are reported here.

OBJECTIVES

In phase one, the objective was to assemble the equipment needed for a portable short range rf sound demonstration unit. Such a demonstration of the rf sound was to be carried out and the unit then used for the experimental work

In phase two, the objective was to combine our experience with the rf sound and the data from vocoder technology in order to experimentally determine if there are rf parameters which will yield the perception of rf sounds of significance.

In phase three, an attempt was to be undertaken to determine if the perception of speech sounds could be induced. The intention was to make such an attempt through the use of buzzes and hisses as is done in vocoder technology.

PHASE 1

A number of equipment assemblies were considered and evaluated within the context of our objectives. The assembly finally selected and obtained consisted of an Applied Microwave Laboratory pulse signal source that was capable of emitting energy at a carrier frequency of 1.2 GHz. The energy was conveyed via a model 871 General Radio Co. air line and RG-8 coaxial cable to a Scientific Atlanta coax to waveguide adaptor and standard gain horn antenna. Within our experimental environment, the horn antenna emitted the energy into an rf anechoic chamber. The antenna was oriented for the demonstration and most of the experimentation such that the energy was horizontally polarized. It was found at the start of the project that vertically polarized energy yields similar effects.

A demonstration of the hearing effect and the effect of varying pulse width, pulse repetition rate, and pulse amplitude was given at USAMERDC.

PHASE 2

In the second phase, three dimensional field plots were made of the rf anechoic chamber that was to be used for the experimentation. The plots were made using the carrier frequency to be used in most of the experimentation. i.e., 1.2 GHz. The measurements were made using a half wave dipole mounted on a wooden pole as the in-chamber pickup. The dipole antenna was supported by a wooden pole in order to minimize field disturbance during the measurement.

In addition to field plots, in each specific experimental session measurements were taken using the half wave dipole antenna located in a position which was approximately the same as the location of the center of the subject's (S's) head during data collection. The dipole was connected via RG-58 coaxial cable to a microlab model AF 20 attenuator that was located outside of the chamber. The attenuator was connected to a Hewlett-Packard model 477B thermister mount and the mount to a Hewlett-Packard model 430C power meter. The cable within the chamber was oriented for minimal field disturbance. This measurement equipment yields an average power measurement from which peak power is derived by the standard duty cycle formula. The signal attenuation due to the cable and the attenuator are accounted for in the reported measurements. The reader should keep in mind the inherent and unspecifiable error in all rf measurements due to the effect of the measuring instrument in the field and the effect of biological objects in the field.

After exploratory experimentation, a series of experiments designed to obtain data on perceived loudness and "sound" quality as a function of various rf parameters was initiated. This was necessary in order to gain an understanding of the effect of the rf parameters on perception. It was expected that from such a data base we could move to generating meaningful sound.

In the first data collection series, a judgement task was set for the subjects. The task was to determine which rf sound of a pair was louder. The test consisted of one standard pulse amplitude and 5 differing pulse amplitudes which had the characteristics shown in Table I. As can be seen in the table, the pulse widths were varied with the standard pulse having a pulse width that fell between the two extremes. The duty cycle also varied as did the average power. The peak power was kept constant. For the first test series,

Table I

Rf Parameters Used at Each Test Condition Number Shown in the Figures

Test Condition #	Pulse width	Duty cycle	Average Power	Peak Power
	μs	$x10^{-3}$	mw/cm^2	mw/cm^2
Standard Pulse	40	[illegible]	.28	140
1	60	3.0	.42	140
2	50	2.5	.35	140
3	30	1.5	.21	140
4	20	1.0	.14	140
5	10	0.5	.07	140

we had 4 subjects compare the "sound" induced by the standard pulse to the "sound" induced by the 5 variable pulses through 10 repetitions. This was done over several sessions for each subject.

Each subject was placed in the rf chamber and he was told the following: "Your job is to determine the loudness of certain sounds. A light will flash on to signal that a sound is coming. After the first sound, there will be an 8 second pause after which you will hear a second sound. You are to indicate which of the two sounds is louder. This is done by pressing button #1 on a hand switch if the first sound is louder or pressing button #2 if the second sound is louder. The first sound you hear is a standard sound and will always remain at the same loudness. The second sound will vary and be either louder or softer. The direction and the amount that it varies has been predetermined by a table of random numbers. Consequently there is no organized pattern to the second sound changes. The test has been set up so that the second sound may not be heard in all cases. In the event that you can't hear the second sound within 10 seconds or so after the first, then you should signal that the first sound is louder by pressing button #1. In this type of test, sounds can not be repeated. So when the light flashes on be prepared to listen. You can not say that the sounds are of equal loudness. You must choose which of the two sounds seems the loudest."

After the series was completed, histograms were constructed from the average results for each of the subjects and one total average histogram was computed. From the individual histograms it was determined that all the subjects had problems distinguishing loudness levels between pulses 1, 2, and 3. In all cases the subjects seemed to have no trouble distinguishing between pulses 4 and 5, and the standard pulse. The results are shown in Fig. 2.

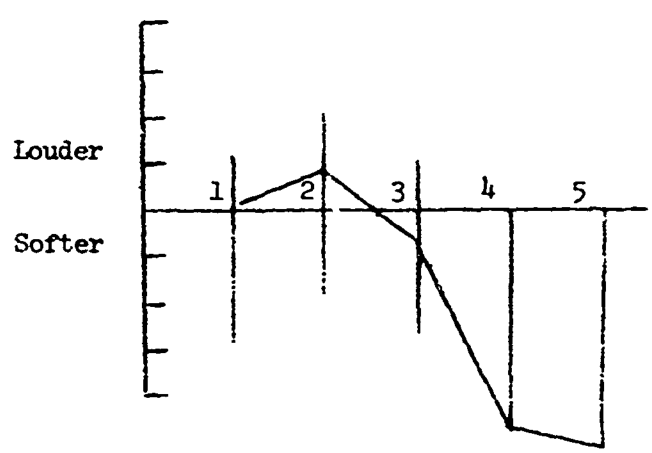

Fig. 2 Histogram of means of subjects exposed to rf energy of characteristics shown in Table I. Peak power was held constant.

TABLE II

Rf Parameters Used at Each Test Condition Number Shown in the Figures

Test Condition #	Pulse width	Duty cycle	Average Power	Peak Power
	μs	$x10^{-3}$	mw/cm^2	mw/cm^2
Standard Pulse	40	2.0	0.735	368
1	60	3.0	1.225	368
2	50	2.5	0.920	368
3	30	1.5	0.555	368
4	20	1.0	0.368	368
5	10	0.5	0.184	368

TABLE III

Rf Parameters Used at Each Test Condition Number Shown in the Figures

Test Condition #	Pulse width	Duty cycle	Average Power	Peak Power
	μs	$x10^{-3}$	mw/cm^2	mw/cm^2
Standard Pulse	40	2.0	.22	110
1	10	0.5	.22	440
2	20	1.0	.22	220
3	30	1.5	.22	146
4	50	2.5	.22	88
5	60	3.0	.22	73

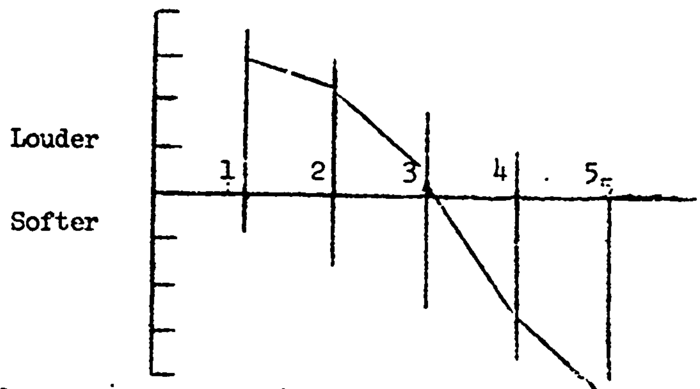

Fig. 3 Histogram of means of subjects exposed to rf energy at characteristics shown in Table II. Peak power was held constant.

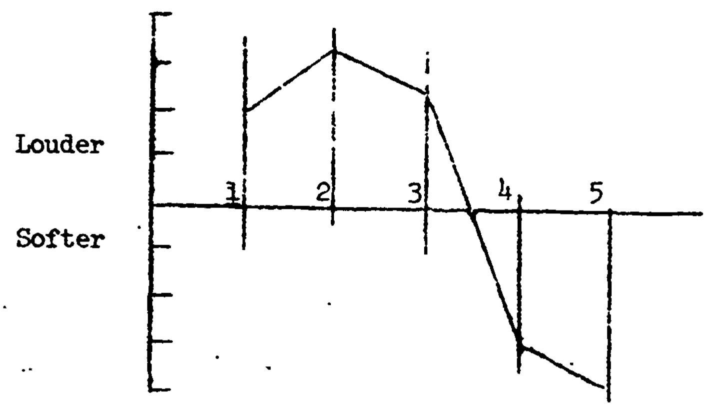

Fig. 4 Histogram of means of subjects exposed to rf energy at characteristics shown in Table III. Average power was held constant.

Based upon this set of data, two further series of tests were designed. In these series, ten subjects were used. Two subjects were used in a test series that once again held peak power constant and varied average power. The parameters are shown in Table II. In another series, the other 8 subjects were used to explore the effect of holding average power constant and varying peak power. The rf parameters used are listed in Table III. After these series were completed, histograms were constructed for the two test series. The histograms of the averages are shown in Fig. 3 and 4. The results shown in Fig. 3

are comparable to those in Fig. 2 as expected. The data that resulted in the averages shown in Fig. 4 indicated that the subjects had little or no trouble distinguishing which of the pulses were louder or softer than the reference pulse. It can be seen in Fig. 4 that pulse number 1 was sometimes considered softer than the standard pulse. One reason for this might have been that pulse number 1 was a very narrow pulse i.e., 10 μs. As one subject described it, he felt that he was listening through the sound. "The sound seems very weak, lacking in depth." This suggested that another parameter had to be considered in our attempt to generate meaningful sound. At this point in time, we discovered a problem unique to the rf sound phenomena. Paradoxical effects can occur when a subject is overtrained for the job i.e., has greater musical background than is required. When such a subject listens to a narrow pulse induced sound he has the impression that these pulses are softer than the standard rf sound. But instead of reporting the expected, he decides that there is a pulse width difference and that such rf sounds are not truly softer. As a result, he reports them as louder. Very careful instructions are needed to handle such problems as well as thorough debriefings after each session.

In the next test series, we explored pulse repetition rate effects with two subjects. The pulse width was fixed at 30 μs and the repetition rate was varied from a low of 50 pulses per sec (pps) to a high of 200 pps. The standard pulse was set at 125 pps. It was found that the subjects tended to cue on repetition rate rather than peak power. It was also found that the quality of the sound changed as a function of repetition rate and that repetition rate was the dominant parameter.

We also explored the effect of different patterns of rf pulses on perception with the use of our special purpose minicomputer. We programmed the computer to so control the rf source that we obtained moment to moment changes in pulse repetition rate. In this way we were able to explore the effect of PRF on the perception of what might be called pitch. It was not true pitch in that we found that there were very real timbre characteristics in the rf sounds generated in this way. We also explored putting these complex modulation patterns on magnetic tape and controlling the rf source in this fashion. In this we met with a qualified success. Spurious signals did present problems.

At this point, it was decided that we had enough information to design a test series to obtain precise data on critical parameters and to gather data on thresholds. New subjects (so that they would be unbiased) with extensive musical training were recruited. Upon applying for a position on the panel the potential subject was first screened with the Gordon test of personality to assure that panel members would be reliable. The potential panel member, after taking this test, was further screened by taking the Seashore Test of Musical Ability. This test provided data on sensory capability in the areas of loudness, rhythm, tonal memory, timbre and sense of time. All panel members accepted had clinically normal hearing. With these subjects a test series was undertaken to answer the following questions in a precise manner:

Is perceived loudness a function of peak power density, average power density, or both?

What is the required energy density for perceptual threshold?

Is there a minimal or optimal pulse width?

The psychophysical technique of magnitude estimation, a well used technique in the auditory area, was selected for use in these experiments. Four well trained subjects provided the data reported herein. Each subject was tested individually within the rf anechoic chamber. The S sat on a wooden stool with his back to the horn antenna. The subject's head was fixed in space by having him place his chin on an acrylic rest mounted on a vertical wooden pole. The subject held in his hand a multi-key hand switch to signal to the experimenter a number as a report of the loudness that he perceived. The subject was told that the first sound he would hear would be a reference sound that was assigned the number 100. He was further told that the second sound he heard would be variable in loudness. It was the S's task to assign a number to the loudness of the second sound with reference to the first sound. The reference sound was selected as being approximately mid-range in loudness.

In the experimental sessions, the experimenter signaled the subject that a trial was about to begin by use of a brief dim light signal. After a variable period of up to five seconds the reference rf sound was presented for two seconds. After a silent period of approximately five seconds, the variable loudness rf sound was presented for two seconds. The S would then use the hand switch to indicate the number he assigned to the loudness. On some occasions, in order to account for the possibility of false positives, no rf sound was presented at the time that the variable rf sound should have been presented. Before starting a session, the subject was given two warm-up trials. The variable rf parameters that were used are presented in Table IV. Each test condition number is defined by a specific peak power, average power, pulse width, and pulse repetition rate. The order of presentation of these sets of rf parameters was randomized by use of a table of random numbers. There were three randomized repetitions of the series.

The primary results are presented in Fig. 5. The point plotted at each test condition number represents the median of all subjects and all repetitions. The plot shown in Fig. 5A was derived from a test series in which we studied

Table IV

Rf Parameters Used at Each Test Condition Number Shown in the Figures

	Peak power varied condition						
Test condition number	1	2	3	4	5	6	6A
Peak power(mw/cm^2)	90	105	125	210	315	630	630
Average power* (w/cm^2)	0.32	0.32	0.32	0.32	0.32	0.32	1.26
Pulse width (μs)	70	60	50	30	20	10	40
Pulses per sec	50	50	50	50	50	50	50

	Average power varied condition					
Test condition number	1	2	3	4	5	6
Peak power (mw/cm^2)*	370	370	370	370	370	370
Average power (mw/cm^2)	0.19	0.37	0.55	0.93	1.11	1.29
Pulse widths(μs)	10	20	30	50	60	70
Pulses per second	50	50	50	50	50	50

* Constant values shown were rounded for clarity.

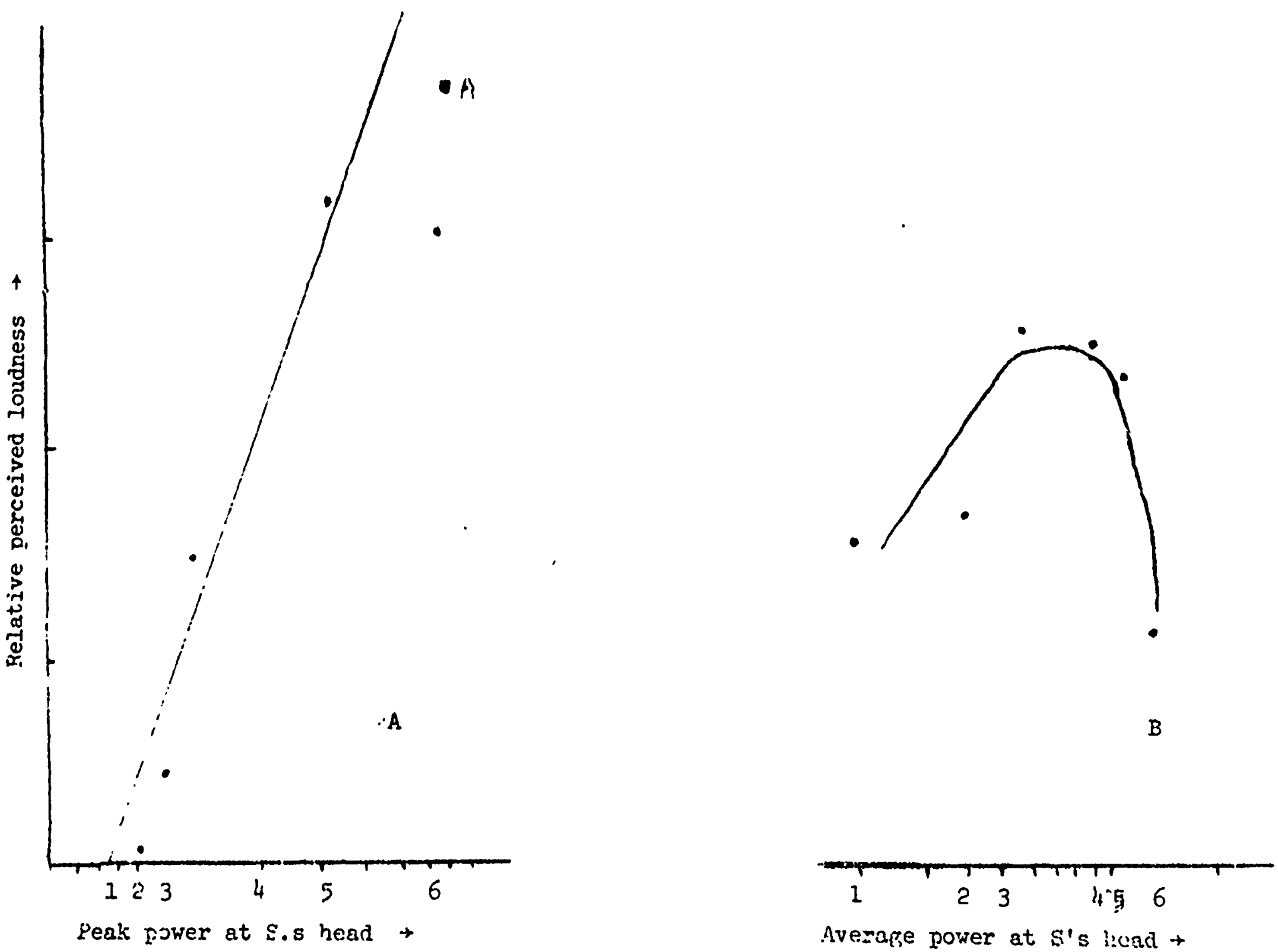

Fig. 5 Perceived loudness as a function of power density.

the effect of varying peak power while holding average power constant. The average power was held constant by varying pulse width. The plot shown in Fig. 5B was derived from the results obtained in a series of tests in which the average power was varied while the peak power was held constant. The data obtained were stable as is typical from trained subjects in psychophysical experiments. A consideration of the two plots indicte that once a minimum pulse width is used, perceived loudness is a function of peak power density. The curves fitted to the data are estimated and are intended only as a guide to the reader's eye. The ordinate is not labeled since the units are arbitrary and could be misleading.

Note should be taken in Fig. 5A of the point plotted for test condition number 6. Its location is inconsistent with what would be expected.

The average data represented by this point were obtained when a 10μs pulse width was used. Since a consideration of all the data shown in the figures indicates that this pulse width is outside the optimal pulse width band for loudness, we tested the possibility that the apparent inconsistency is due to the use of a non-optimal pulse width. We tested by obtaining data using the same peak power but with a pulse width within the optimal band, i.e., 40μs. The average of the data so obtained is represented by the square labeled A in figure 5B. It indicates that the apparent fall off in perceived loudness as peak power is increased at test condition 6 is due more to the pulse width being less than optimal for full perceptual effect than to an actual drop off in perceived loudness at the higher peak power levels. Note should also be taken that the data plotted in Fig.5B suggests that beside an apparent minimum pulse width for perceived loudness there may also be a maximum pulse width defining a band of optimal pulse widths for perceived loudness. It also appears that average power does not determine loudness except insofar as it is incidentally involved due to the need for a minimum pulse width for optimal effect.

The required energy density for perceptual threshold was derived by simply extending the curve in Fig. 5A to the abscissa. In this manner, a threshold peak power density of 80 mw/cm^2 was derived. This threshold was not derived with the use of optimal rf parameters and is clearly not the lowest value that can be obtained for threshold. The average power density, though conventionally given, is not particularly meaningful with this phenomena. In this case it was approximately 0.3 mw/cm^2 but could have just as easily been 3 $\mu w/cm^2$. We need only have reduced pulse width and pulse repetition rate.

With this full set of data on perception as effected by the various rf parameters, we were able to begin constructing rf sounds that might be meaningful to the subjects. In our quest to generate meaningful sounds, it was found that by externally modulating the microwave source with one or two pulse generators it was possible to generate rf "sounds" that people could recognize as having meaning. These sounds included bongo drums, lawnmower engines, small model airplane engines, electric saws, crickets, knocking on doors, and tapping of a pencil.

To create these rf sound perceptions, it was first necessary to determine what characteristics the acoustic sound in question had, e.g., sharp, piercing, dull, flat, fast, slow, repetitive, etc. This was done using pulse generators, a speaker and several musically trained subjects. The subjects then assisted the experimenter in the creation of a perceptually similar rf sound. The general rule of thumb was found to be that any sound that could be created using the pulse generators and the speaker could be created as an rf sound with knowledge of its acoustical characteristics and the knowledge we had obtained on rf sound characteristics. After the rf sound had been created to the best of the experimenter's ability and within the limitations of the rf equipment, it was listened to individually by several subjects. Each subject would evaluate the sound and give his impressions of it. The parameters of various sounds are listed in Table V.

With this rather substantial base of information, we felt prepared to create a meaningful sound without the time consuming use of subjects. We chose to create the sound of an incoming bullet as a sound to test our knowledge. We obtained a tape recording of such sounds and analyzed this tape thru the use of our oscilloscopes. We then set out to create an rf sound which might yield a comparable perception to our subjects.

To achieve an incoming sound it was necessary to use an AEL pulse generator to trigger an SCR circuit which controlled an rf pulse generator. This was done as follows: The secondary of a 12 volt step down transformer was placed in series with the output of the AEL pulse generator. This in turn was connected to the gate of the SCR. With the AEL generator off, the circuit was so adjusted so that the SCR would fire at full potential. When the AEL was on, the output opposed the voltage flowing into the gate. In this way when the AEL was firing the voltage to the gate was reduced which in turn reduced the output at the SCR circuit.

The output of the SCR circuit was fed into the microwave source's power supply. The power supply stepped up the voltage then rectified and smoothed the voltage to a DC level which was selectable between 0 - 5000 volts. This 0 - 5000 volt DC level controlled the output power at the microwave source. The circuit is shown in Fig. 6.

Table V

Various Rf Parameters to Generate Meaningful Rf "sounds"

Sound	Parameters needed to create the sound		
	Rep rate (pps)	Pulse width (μs)	Special notes
Bongo Drum	50	5-50	Sound was thin, double pulse improved the quality of perception.
Cricket	8-25	5-50	The repetition rate randomly varied between 8 & 25 pps.
Lawnmower	0.8	30	The pulse generator was set in the trains position with a train that varied between 0.1 to 1.0 ms.followed by a delay of 13 ms. This produced a sound like a lawnmower laboring in deep grass.
Tapping	800	5-50	The pulse generator was set in the trains position with a train of 1.5 ms and a delay of 100 ms. This setting was also described as knocking on a door, when the delay was varied in a random fashion between 80 and 100 ms.
Model Airplane	50	5-50	To generate this sound it was necessary to have two pulse generators triggering the microwave source. One pulse generator was constantly running. The second was set in the trains position with a train of 2 seconds and a delay of 3 seconds.

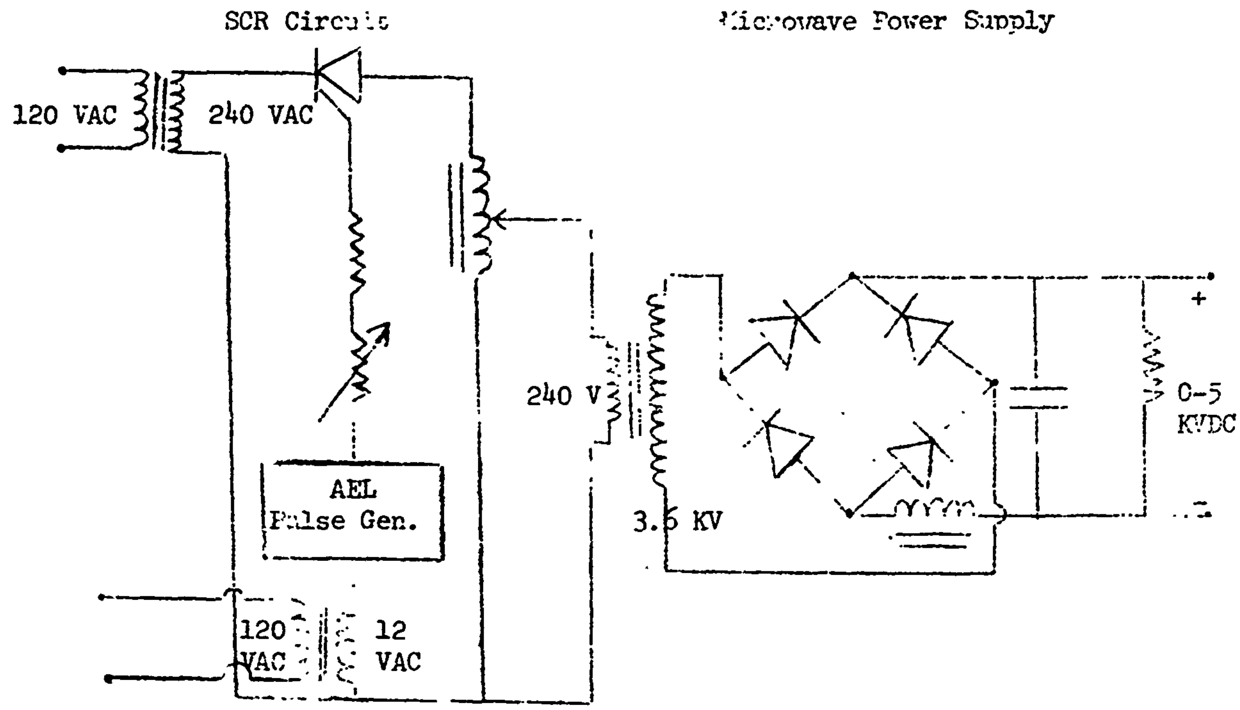

Fig. 6 Circuit diagram of SCR pulse generator circuit used in conjunction with the microwave power supply.

To generate an incoming sound it was necessary to use this circuit to change the rf amplitude. The pulse width and repetition rate were fixed at 12 μs and 847 pps respectively. The amplitude of the rf signal had to have a rather low level of sound for about 4 seconds. Then an abrupt rise in sound for 0.5 sec. To do this the AEL pulse generator was set to generate a train of pulses 4 seconds long with a 0.5 second silent period before another train started. Within this train were positive going pulses at a frequency of 50 pps. This would create a low level output from the SCR circuit for 4 seconds with a 0.5 second high period.

When the low output of the SCR circuit was fed into the power supply the internal circuitry of the supply would change the low level to about 1500 VDC. When the 0.5 second high output of the SCR circuit was fed into the power supply circuit the internal circuitry would change the high level to about 5 KV DC.

When the 0.5 second high level [illegible] completed the 5 KV voltage would decay exponentially due to a smoothing capacitor in the circuit. This made the rf incoming "sound" appear to have passed the listener. A typical waveform at the rf source is shown in Fig. 7.

Fig. 7 Typical rf waveform

The subjects reported that the rf sound, though low in intensity, sounded like the tape recorded incoming bullet sound. This effort established that meaningful rf sounds could be constructed. It also showed that an rf source with unique control circuitry would have to be designed and built for the creation of specific meaningful sounds. Although we were able to design and build control circuitry to accomplish what we wished with a standard rf source, it was a marginal situation in getting it to operate and maintaining operation.

PHASE 3

Having established that a specific sound could be created, we entered into phase three of the project. From the data obtained to this point it was clear that because of the nature of rf sound transduction, the acoustic procedure used in vocoders could not be applied. The quality differences and timbre characteristics of rf sound discovered to be a function of repetition rate would not allow the construction of speech from simple buzzes and hisses. A buzz, for example, would not retain its character as frequency was changed for tonal components would enter into the perceived "sound" with the rf sound phenomena.

Thus, we explored the possibility of using the periodicity pitch phenomena from acoustics as a means of generating the perception of speech sound. In acoustics, presentation of a train of acoustic pulse pairs to a subject results in the subject reporting the perception of a tone whose frequency is primarily a function of the time within pulse pairs. This is the periodicity pitch phenomena. We tested to determine if there is an analogous situation with the rf sound. The test series was run double blind with our musically trained subjects.

Employing the data supplied by Bilson and Ritsma on periodicity pitch and the specifications of Ritsma dealing with residue pitch (a related phenomena), we chose the ten signal conditions and ten expected tonal matches which are presented in Table VI. Repetitive rf pulse pairs were used. We define t as the period of each pulse, τ as the interval between the onset of pulses in a pulse pair, and T as the interval between the onset of pulse pairs. To clarify these values, we note that t is less than τ is less than T. The objective was to present the Ss with trains of pulse pairs with defined t, τ and T and predict the acoustic sound that they would report. The experimenter asked the subjects to match the rf sounds with a pulsed acoustic signal to determine the Ss perception of the rf sound. The pulse width of the acoustic signal was 1.5 milliseconds. Once the best repetition rate audio match to the rf sound had been obtained, the experimente. asked the S to match the same rf sound to a pulse modulated audio signal having the repetition rate specified as above by the S but wit..

Table VI

Rf Parameters for the Pitch Study Along with Expected Results

Condition	$\bar{t}$(μs)	τ(ms)	T(ms)	Expected Tonal Match
1	25	5	40	200 Hz
2	25	3	20	333 Hz
3	50	5	40	200 Hz
4	50	10	40	Unmatchable buzzing sound or 100 Hz
5	25	5	200	Unmatchable or 200 Hz
6	12.5	5	40	200 Hz
7	17.5	2	20	500 Hz
8	12.5	1	20	1000 Hz
9	12.5	7	40	143 Hz
10	37.5	7	40	143 Hz

a varying pulse width. E recorded the S's match for both repetition rate in pulses per second and audio pulse width in milliseconds. The audio match was obtained by utilizing audio signals of approximately the loudness of the rf sound. The order of the rf conditions under investigation for periodicity pitch were varied throughout the study by use of a table of random numbers.

The general procedure was as follows. An S would take a seat in the rf anechoic chamber with his back to the horn antenna. The S would be presented with an rf sound for 2 seconds and then would listen to an audio sound and instruct the investigator as to how the audio sound had to be changed to compare with the rf sound. The E had control over the modulation characteristics of the audio sounds and could vary these characteristics according to the verbal instructions given by the S. After switching back and forth between the rf and the audio several times the subject would verbally give his impressions of the rf sound and, if possible, assign a note to it. To facilitate the finding of a note the subject was given a pitch pipe. To help with the assigning of an octave the S could listen to a note played on a piano at 10 octaves.

The subjects were told the following: "You are going to help us to determine the pitch of a sound by trying to match up an rf sound to an acoustic one. This will be done by first listening to an rf sound then listening to an audio sound speaker over your head (out of the rf field). At this point you will instruct me whether or not to change the pitch of the audio sound. We are only concerned with pitch, all other qualities such as loudness and sharpness of the two sounds should be ignored. After a match has been established, if possible try and tell me the frequency of the pitch that you hear. You may either relate the pitch to a note whose pitch is known to you, or you may just tell me the exact frequency of the pitch."

The audio match supplied by each of the three subjects to each of the 10 conditions is illustrated and compared with the expected values in Tables VII and VIII.

As may be seen, the audio pulse width time (ta) does not relate to any of the variables which describe the rf signal. In particular, ta is not related to the pulse width time (t) of the rf signal, nor to the pulse repetition time within groups (τ), nor to the pulse pair repetition time (T). Apparently the repetition pitch phenomenon is not a characteristic of rf sound.

As a further test of the repetition pitch phenomenon, subjects had been asked to provide a note and octave match to the rf sounds that they perceived. In many cases, the subjects stated that they could not provide such a match. When

Table VII

Parameters of 10 rf conditions along with expected and actual time between pulse pairs (T)

					Subjects Ta match for 10 conditions					
							Subjects			
	t(μs)	τ(ms)	T(ms)	Expected	IA	IB	IIA	IIB	IIIA	IIIB
Condition				Ta(ms)	Ta(ms)	Ta(ms)	Ta(ms)	Ta(ms)	Ta(ms)	Ta(ms)
1	25	5	40	40	43	25	20	54	52	44
2	25	3	20	20	44	28	21	24	24	24
3	50	5	40	40	42	44	29	21	50	43
4	50	10	40	40	38	40	36	28	43	43
5	25	5	200	200	210	425	150	85	200	200
6	12.5	5	40	40	35	40	50	24	50	43
7	17.5	2	20	20	20	27	20	20	20	25
8	12.5	1	20	20	50	30	20	30	23	22
9	12.5	7	40	40	23	37	20	25	38	31
10	37.5	7	40	40	30	23	30	38	50	44

Table VIII

Parameters of 10 rf conditions along with expected and actual pulse width (t).

				Subjects ta matbh for 10 conditions						
Condition	t(μs)	τ(ms)	T(ms)	Expected ta(ms)	IA ta(ms)	IB ta(ms)	IIA ta(ms)	IIB ta(ms)	IIIA ta(ms)	IIIB ta(ms)
1	25	5	40	5	20	x	60	20	40	20
2	25	3	20	3	x	0.5	60	20	20	20
3	50	5	40	5	x	0.5	60	20	40	20
4	50	10	40	10	x	0.5	20	20	20	20
5	25	5	200	5	100	0.1	20	20	20	20
6	12.5	5	40	5	x	0.5	20	20	20	20
7	17.5	2	20	2	x	0.5	20	20	20	20
8	12.5	1	20	1	x	20	20	20	20	20
9	12.5	7	40	7	x	0.5	20	20	20	20
10	37.5	7	40	7	x	30	60	20	40	20

x = range of 2 - 30 μs

Table VIII

Parameters of 10 rf conditions along with expected and actual pulse width (t).

				Subjects ta match for 10 conditions						
Condition	t(μs)	τ(ms)	T(ms)	Expected ta(ms)	IA ta(ms)	IB ta(ms)	IIA ta(ms)	IIB ta(ms)	IIIA ta(ms)	IIIB ta(ms)
1	25	5	40	5	20	x	60	20	40	20
2	25	3	20	3	x	0.5	60	20	20	20
3	50	5	40	5	x	0.5	60	20	40	20
4	50	10	40	10	x	0.5	20	20	20	20
5	25	5	200	5	100	0.1	20	20	20	20
6	12.5	5	40	5	x	0.5	20	20	20	20
7	17.5	2	20	2	x	0.5	20	20	20	20
8	12.5	1	20	1	x	20	20	20	20	20
9	12.5	7	40	7	x	0.5	20	20	20	20
10	37.5	7	40	7	x	30	60	20	40	20

x = range of 2 - 30 μs

subjects did provide a match, they were not consistent. Two subjects do not associate the same tone with the same rf condition, and they were never satisfied with a match. Finally, in cases where we would expect the matched tones to be higher than other cases, based on the repetition pitch phenomenon, we found that whether the tone match was higher or lower was a matter of chance.

Thus, the periodicity pitch phenomena is not the path to pursue in order to generate speech sounds. We could conclude from this phase three data that it would be necessary to have a better understanding of the rf sound transducer and its mechanism before it will be possible to generate speech sounds.

CONCLUSIONS

In the first phase of the experimentation, we assembled a portable rf sound demonstration unit. This was successfully used to demonstrate the phenomenon and its characteristics. In phase two, we determined what rf parameters are relevant to generating the perception of rf sounds of significance. We learned enough in this phase to successfully create a perceived sound that we desired to create. In phase three, we explored the possibility of determining if the perception of speech could be induced. It was found that aspects of vocoder technology could not be used to generate speech. It was also found that perceived rf speech can not be generated using the rules of the periodicity pitch phenomenon. It would appear that meaningful sounds can be created if desired. The possibility of creating speech, however, is uncertain. The creation of speech, if it is possible, will require additional knowledge of the mechanism of the effect.

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